Table 1

Comparison of toughened and non-toughened composite laminates.

Examples	Product	% Volume Fraction Structural Component	Structural components
Example 4	(F394)	22-23	Glass/polypropylene/ polyester
Example 5	(F404)	41	Glass/polyester
Example 6	(F384)	22-23	Glass/polypropylene/ polyester
Example 7	(F389)	25	Glass/polyester

The structural components each comprised about 50:50, glass to toughening additive, by volume.

Figure 3 shows the impact results for the Examples 4-7 as a plot of absorbed energy against thickness x volume of fibres. The impact master curve for SMC (sheet moulding composite), GMT's (glass mat thermoplastics) and prepreg etc. has been superimposed for comparative purposes. The absorbed energy for the polypropylene and polyester containing composites is significantly improved by comparison with analogous composites having no toughening additive.

Figures 4 to 6 are plots showing impact strength, that is, energy absorbed during penetration, as a function of thickness x volume fraction of fibres. Each plot has data from three different thermoset matrices – two epoxies and a polyester. The first plot of Figure 4 shows the results achieved when glass fibres alone are used with the volume fraction of glass fibres in the composite being between 30 to 50%. The second and third plots of Figures 5

and 6 show the results when the portion of the glass fibres is replaced by polypropylene, Figure 5, and polyamide, Figure 6. The plots demonstrate that the inclusion of the thermoplastic polymers provide significant benefits in terms of improved impact strength. Furthermore the effect is consistent with different matrices.

The resins used in the study which produced the plots of Figures 4 to 6 included an unsaturated isophthalic polyester resin (UP), Crystic 272 (a product of Scott Bader plc) and two epoxy systems, EP1 was a cold cure epoxy resin (digylcidyl ether of bisphenol A cured with an amide hardener (Shell Epikote 828 cured with Ciba HY932 aromatic amine) and EP2 was a low single-part, low-viscosity epoxy resin supplied by Cytec-Fiberite, Cycom 823, which was cured at 120°C.

The experimental procedure in all of these tests involved the use of an instrumented falling weight impact test in which a striker equipped with a 20 mm diameter hemispherical tip is allowed to fall onto a plate specimen of the test composite. The composite specimen is a thin plate, typically 3mm thick, and 60mm x 60 mm in size which is simply supported on a steel ring with an internal diameter of 40 mm. The striker is dropped from a height of 1m and has sufficient mass such that the kinetic energy is sufficient for the striker to completely penetrate the specimen. The test records the forces during the impact event and the energy absorbed is calculated from the force time record and the measured velocity of the striker as it impacts the specimen.

The use thermoplastic fibres incorporated into the resin matrix provides a thermoplastic region in the thermosetting matrix which gives a mechanism for plastic deformation and yielding which is not possible in the unmodified thermosetting resin on its own. The low viscosity of the unmodified thermosetting resin makes it feasible to mould large parts in reasonable time periods and to use low injection pressure for the process which will also eradicate any problems with fibre wash near the injection points due to the applied pressures.

The invention has the potential to make a number of composite fabrication techniques more effective in being able to handle a greater range of matrix formulations and their efficiency with existing systems can be increased as flow and wet out times can be reduced. This will result in a reduction in the time taken to manufacture a component.